A novel eMandible system for mandibulectomy design and free flap reconstruction

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Introduction

The goal of this study is to develop an open-source systems-imaging-informatics-platform, ***eMandible***, for clinicians to automatically and accurately estimate patient-specific ablation and fibula remodeling for mandibulectomy as well as flap reconstruction for removing oral cancer based on computed tomography (CT), magnetic resonance imaging (MRI), and genomics data. Various surgery procedures have been used to remove oral cavity and oropharyngeal cancers, depending on the cancer location and stages. Reconstructive surgery can be done to help restore the appearance and function of the affected areas after the surgical removal of the cancer. A mandibulectomy is a procedure that is used to eradicate disease that involves the lower jaw or mandible. When a tumor has grown into the jawbone, a mandibular resection, or mandibulectomy, may be needed (see **Fig.1**). The jaw needs to be rebuilt using the bones from another part of the body. The bone may be taken from patient's fibula, which is the smaller bones in the lower legs. An artery, vein, and soft tissues will also be taken with the bone. This procedure is called as fibula free flap (see **Fig.2**).

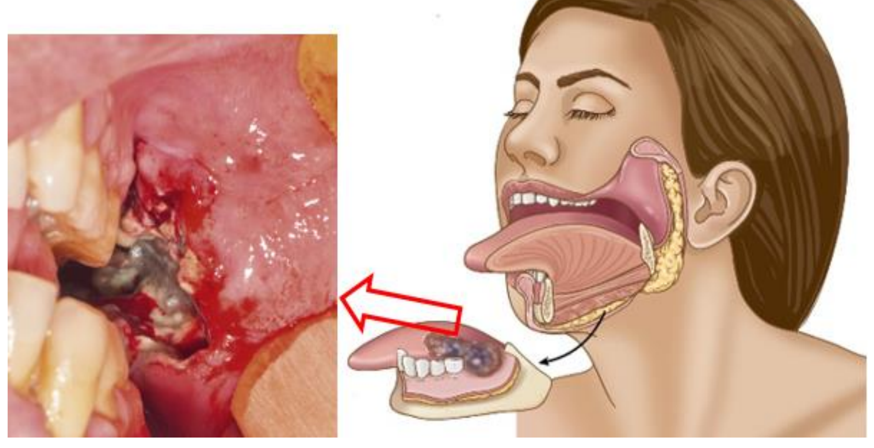

Fig.1: Mandibulectomy.

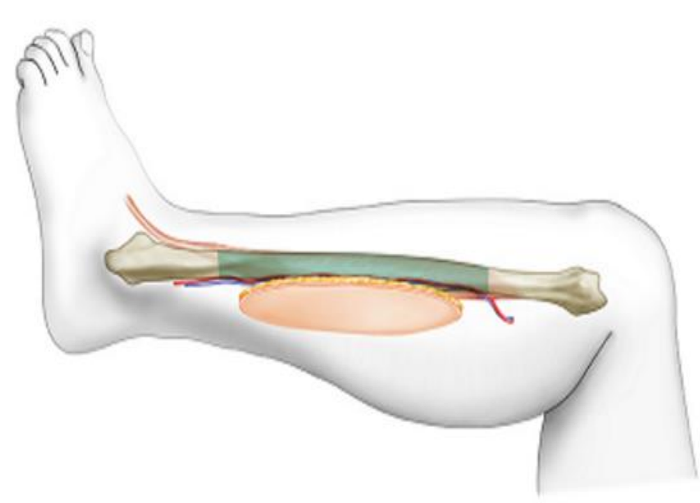

Fig.2: Fibula free flap.

Challenging Issues in Mandibulectomy

The ideal reconstruction will restore the normal appearance and preserve the normal function for chewing, speech, and swallowing. Patient-specific mandible and fibular osteotomies are the principal barriers for the advancement of mandibulectomy and free flap reconstruction. Planning personalized composite resection and osteotomy angles are highly dependent on the experience of a surgeon. **Currently, there is no automated and reliable methods for accurate planning surgical resections of oral cancers and estimate the graft area.**

The Computational Systems Research Strategy

To **accurate planning of composite** oral cancer ablation (bone and soft tissue) and predict patient-specific **graft area** optimally. We *hypothesize* that oral cancer can be accurately detected based on the image features of tumor, and then the **graft area** of each patient can be optimally predicted via biomechanical properties.

Mandibular reconstruction is a challenging task in head and neck reconstructive surgery for achieving optimal functional and esthetic outcomes. The main procedure is described in **Fig.3**.

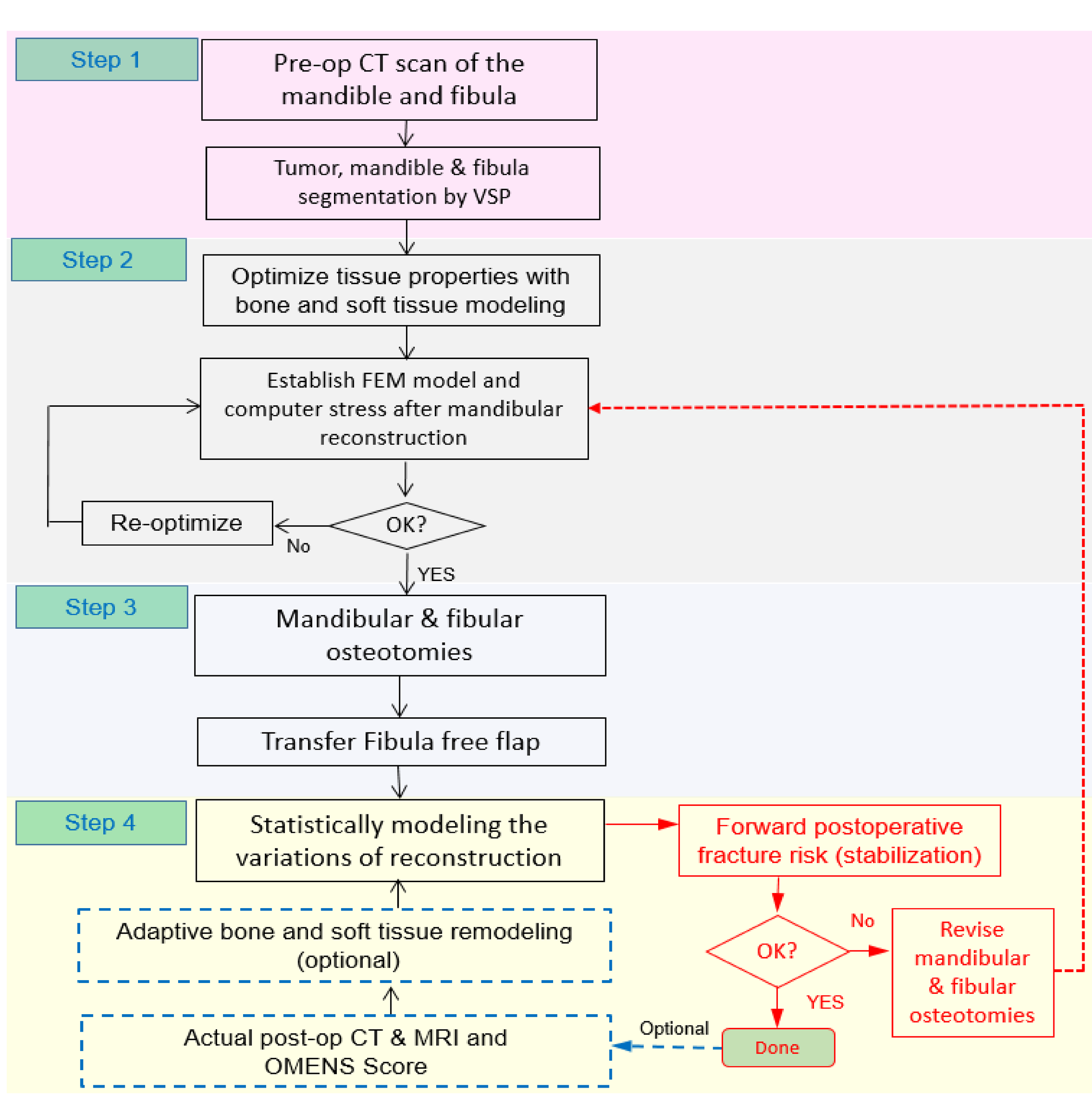

Fig.3: Mandibulectomy and free flap reconstruction.

Mandibulectomy Design and Reconstruction

Using **Virtual Surgical Planning** (**VSP**), resection margins can be determined and the engineer marks the desired cutting paths for the osteotomies (see **Fig.4**). Following virtual resection of the mandible, the virtual vascularized bone flap is superimposed on the ablative defect in the desired vascular and soft tissue orientation. Virtual osteotomies are then designed to fit the flap precisely into the idealized reconstruction with optimal bony apposition (see **Fig.5**).

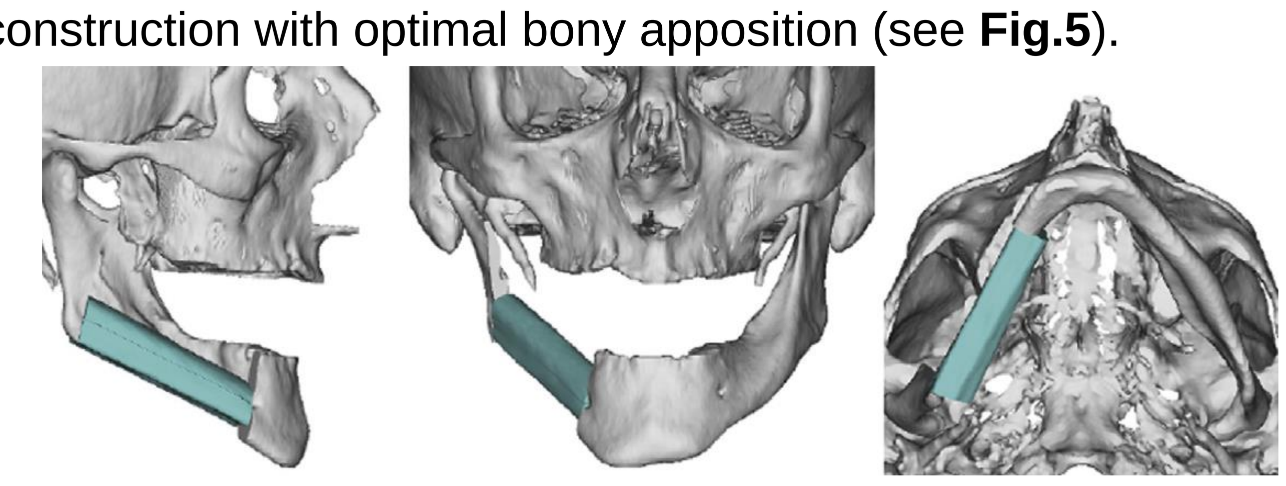

Fig.4: Virtual Surgical Planning (VSP) plan for segmental resection.

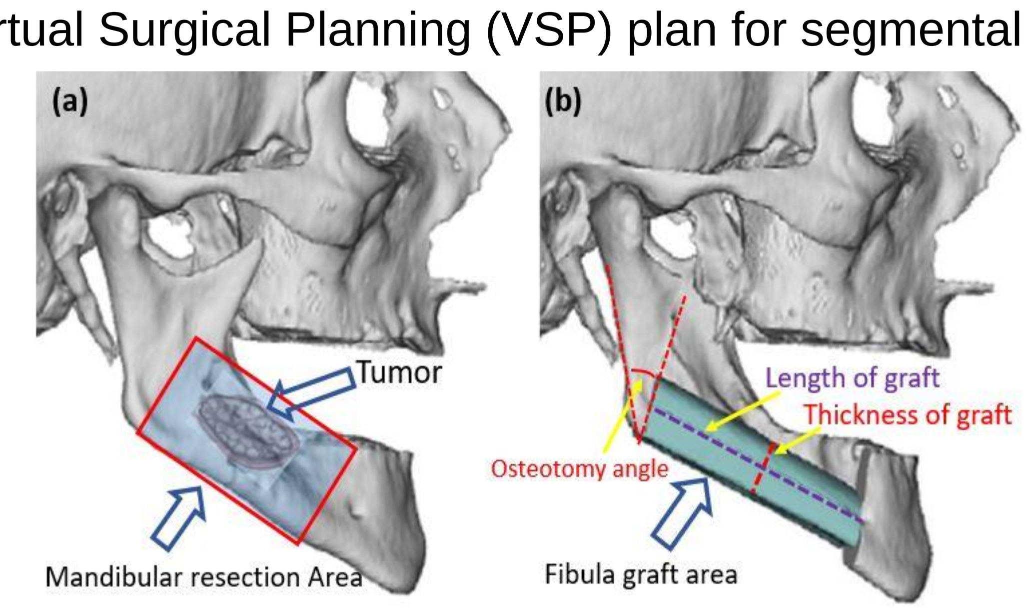

Fig.5: (a) Pre-operation; (b) Post-operation.

Bone and Soft Tissue Regeneration model

We construct a 3D mathematical model based on the CT image to simulate the defect repair process. The model will incorporate multiple physical scales into a consolidated simulation platform. After the tissue (including the bone graft and ambient soft matrix) grows to a threshold volume, the finite element method (**FEM**) (**Fig.6**) will be adopted to analyze the stress and strain within and surrounding the bone graft, by which we can assess the stability of the graft, and power of masticate. We not only focused on the contact region of native mandible bone and graft bone, but also considered the soft tissue regeneration and repair with fibula free flap (**Fig.7**).

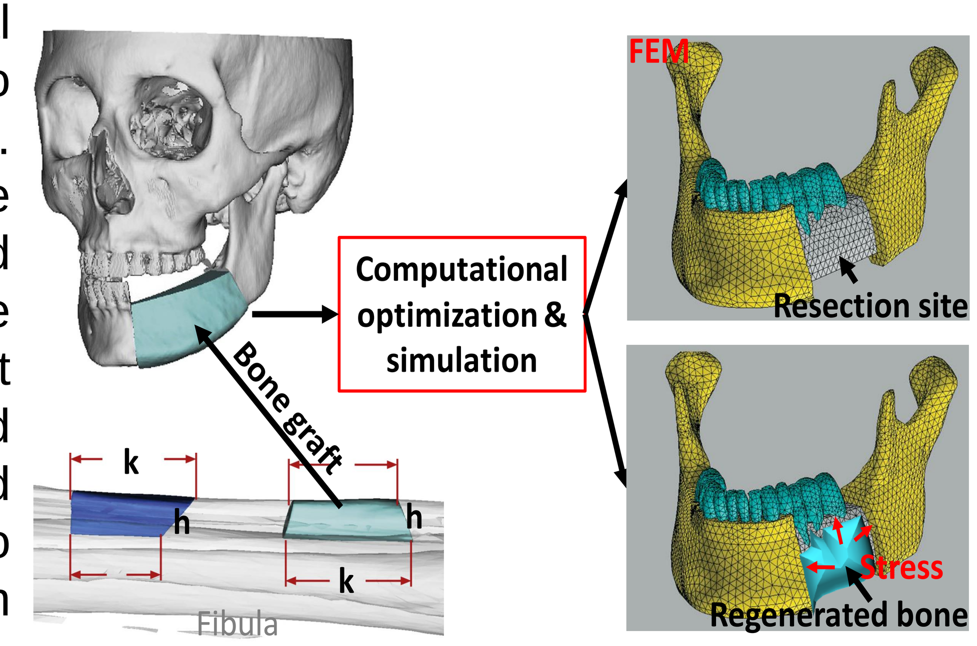

Fig.6: Graft bone regeneration.

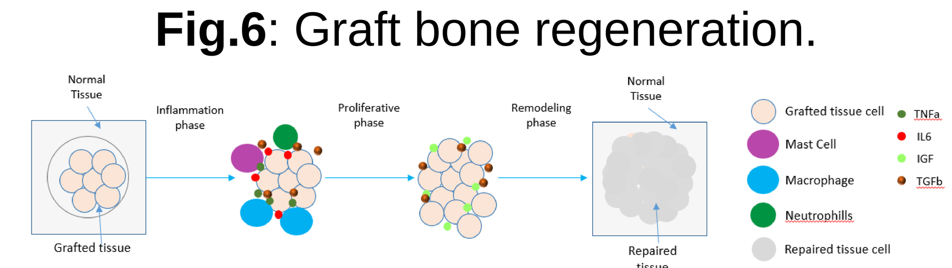

Fig.7: Soft tissue regeneration and repair.

Optimal Graft Area Prediction and Validation

Support Vector Regression (g) is employed to model the stabilization (ΔS) of ith patient by minimizing an objective function as $\|\Delta S - g(\sigma, T, \alpha)\|_{L2\,norm}$ which is calculated from the chewing force F, α is the angle of mandible osteotomy, fibula graft thickness T , and surgical results stabilization (ΔS). When a new patient comes to hospital, the optimal fibula graft thickness T estimation can be done prior to the surgery to ensure a successful operation.

Based on the clinical experience and acceptance, we expect there will be no statistically difference and the absolute mean deviation between the predicted optimal graft size and ground truth will be within 5%.The ***eMandible*** system is expected to meet a gap that now precludes the ability to treat oral cancer effectively. Our system has the potential to produce a paradigm shift in oral cancer diagnosis and treatment.

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